LANDING GEAR

METHOD AND APPARATUS FOR BRAKING AND MANEUVERING

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BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0001] The Invention relates to aircraft landing gear and, more specifically to an integrated wheel hub motor/generator, regenerative braking and/or motorized braking method for an aircraft landing gear system, which reduces wear of the braking system and the associated tires while improving stability of said aircraft and reducing the need for maintenance due to wear.

RELATED ART

[0002] It is known in the field of aircraft wheel and brake assemblies to provide a non-rotatable wheel support, a wheel mounted to the wheel support for rotation, and a brake disk stack using friction braking to convert rotatory motion of said disks into friction heat energy which creates wear of said disks. Various brake actuation configurations and methods are known, as in U.S. Patent No. 4,381,049, 4,432,440, 4,542,809, 4,567,967, 4,596,316, 4,865,162 and 6,615,958.

[0003] The current state of the art for providing braking systems for aircraft uses stators and rotors, which are forced into physical contact with each other thus generating friction heat that introduces wear of the associated disks and requires periodic maintenance to replace the worn parts.

[0004] The primary drawback of carbon disk brakes of the latest designs is that a greater volume of carbon material is needed to absorb the same amount of heat energy as that of steel disk brakes. Another drawback of carbon disk brakes is the diminished braking capacity due to moisture contamination of the carbon surfaces due to rain and the high replacement cost after they are worn.

[0005] Furthermore, aircraft are required to maneuver within the defined taxies, runways and terminals. One such requirement is the 180-degree turn that places an upper limit on the aircraft allowed for a particular runway based upon the width of the runway and the ability of said aircraft in conducting a 180-degree turn there on within the physical width of said runway. Current landing gear provides limited abilities to perform such 180-degree turns.

[0006] One significant concern in aircraft brake design is the dissipation of kinetic energy of aircraft within the braking system of the landing gear system during landing and rejected takeoff conditions. Ultimately, it is the rolling friction present between the tires and the landing surface, which slows the aircraft, thus brake capacity requirements are based upon maximum landing weight of the aircraft and the rolling friction. Braking systems of the prior art are relatively inflexible with respect to the manner in which they generate the required braking force.

OBJECTS OF THE INVENTION

[0007] Accordingly, it is an object of the invention to provide an improved system and method for braking and maneuvering in landing gear of aircraft.

[0008] It is a further object of the invention to overcome the limitations and drawbacks associated with prior art systems for braking and maneuvering in landing gear of aircraft.

[0009] A further object of the invention is to reduce wear of the components involved in the landing gear and braking system, add stability to the aircraft structure, and increase reliability, while reducing the needed maintenance associated with current friction braking systems.

[00010] It is a further object of the invention to reduce the need for friction brake disks within the landing gear of aircraft.

[00011] It is yet a further object of the invention to provide a system and method for recovering kinetic energy from aircraft and convert such energy into electrical power.

[00012] It is a still further object of the invention to provide a system and method for aircraft landing gear, which permits a reduced turn radius for the aircraft.

[00013] Another objective is to reduce the wear of the tires of said aircraft due to sliding friction wear due to touchdown by closely matching the landing gear tires radial velocity with that of the relative ground velocity such that when touchdown occurs the difference in velocity is greatly minimized, thus greatly reducing the sliding friction wear of said tires associated with the touchdown of the landing gear tires with the runway landing surface. This sliding friction, which is present in the current state of the art, creates an associated wear that affects tire performance thus affecting safety.

[00014] A further object is to provide a means of motive force for the purpose of conducting taxiing and ground maneuvers of said aircraft, which contributes to increased efficiency, maneuverability, stability and safety of said aircraft.

[00015] A further object is to provide a means of motive force for the purpose of assisting in takeoff, which reduces the required takeoff distance for the aircraft, which

also contributes to increased efficiency, maneuverability, stability and safety of said aircraft.

SUMMARY OF THE INVENTION

[00016] The present invention provides a unique means of aircraft braking wherein the use of regenerative braking and/or motorized braking is applied in a manner, which creates advantages over prior art friction braking systems. This is accomplished by integrating a wheel hub motor/generator within the wheel and axle structures wherein the braking action is provided for by the magnetic torque interactions of the stator and rotor disk sections of said wheel hub motor/generator. Kinetic energy of said aircraft is converted into electrical power, which may be dissipated through a resistor and/or stored for later use when the aircraft is taking off, taxiing and performing other ground maneuvers, or may be used at the time of landing to increase the effectiveness of the electromagnetic braking system by instituting the use of motorized braking action, thus increasing the overall efficiency of the braking system and adding stability and safety to said aircraft.

[00017] Moreover, it has been discovered that other features present have applications to reduce landing gear tire wear of aircraft by using the wheel hub motor/generator as a motor prior to landing to match the tire radial velocity with that of the relative ground velocity such that when touchdown occurs that there is minimal difference in the two velocities such that sliding friction wear is greatly minimized thus improving life time of landing gear tires thus increasing the performance of said landing gear tires, which adds to the controllability and safety of said aircraft. There is an added benefit in that when the landing gear wheels are motorized in flight they provide a gyroscopic stabilizing effect,

which dramatically stabilizes the aircraft depending upon the speed of rotation of said landing gear wheels.

[00018] In one embodiment, a wheel hub motor/generator disks stack includes alternating rotor and stator disks wherein each rotor disk is coupled to the wheel for rotation and each stator disk is coupled to the axle and/or torque tube for support that is static in relation to the tire rotation. In a preferred embodiment the wheel hub motor/generator functions as a brake by means of generator action also known as regenerative braking wherein magnetic torque interactions between the rotor disk and stator disk sections apply a braking force to the wheel and tire assembly and the electrical power generated is stored for later use.

[00019] The wheel hub motor/generator may have mounted thereon a plurality of associated stator and rotor disk members which may be activated or deactivated individually, sequentially or in unison with the application of an electrical current or generation of electrical current in varying directions depending upon the need for motor and/or regenerative and/or motorized braking action. In one such case electromagnetic braking is applied by using associated rotor and stator disks as a generator and from which the output power from the stator is applied to another stator disk in such a manner as to increase the braking effect of the associated rotor of said other stator disk, thus accomplishing motorized braking action or motoring of a disk or disks which is acting as a generator within the same, or other wheel hub motor/generator, disk stack as that of the generating disk or disks.

[00020] The method of motor/generator electrical interconnections of different stator disk or disks within the same, or other wheel hub motor/generator, disk stack or

motorized braking method as disclosed herein can be varied in numerous combinations of generator disk or disks and motor disk or disks within the present invention and is unique in the area of disk type axial flux motor/generators and offers flexibility in aircraft applications by allowing for the electrical and/or physical addition of disk or disks or removal of disk or disks based upon the aircraft landing weight and/or landing gear design needs. This electrical interconnection of disks in which any disk within the wheel hub motor/generator disk stack may act as a motor or as a generator or in any combination thereof is known as motorized braking method as proposed within the present invention, which adds flexibility to the design of aircraft landing gear. Incorporating the use of disk type axial flux motor/generators greatly reduces design cost due to this flexibility in motoring and braking of said motor/generator.

[00021] As noted above, one concern in aircraft brake design is the dissipation of kinetic energy of aircraft within the braking system of the landing gear system during landing and rejected takeoff conditions; ultimately, it is the rolling friction present between the tires and the landing surface which slows the aircraft, and thus brake capacity requirements are based upon maximum landing weight of the aircraft and the rolling friction. The method of motorized braking in accordance with the invention introduces flexibility in generating the required braking force that is lacking in the present state of the art braking systems, and allows for more efficient designs in that an overloaded aircraft can increase the amount of braking capacity by means of altering the electrical connections through switching controls thus increasing the safety of the aircraft.

[00022] Furthermore, by implementing the use of disk type axial flux wheel hub motor/generators within the landing gear said aircraft is able to reduce the turn radius in

which a 180-degree turn may be accomplished by means of motoring one set of landing gear in one direction and motoring the other set of landing gear in the opposite direction, this method of turning thus allows said aircraft to complete a 180-degree turn within a smaller turning radius as opposed to that of the current state of the art landing gear, due to the fact that the center of rotation of the present invention is located between the main landing gear on the center line of said aircraft and not at the intersection of the lines extending from the axes of the nose gear and landing gear as with current state of the art landing gear. This feature provides for reduced runway surface wear due to the lack of need to lock up the brakes on the pivoting landing gear assembly and eliminates the associated wear of the tires of the pivoting landing gear assembly due to the sliding friction, which is present in the current state of the art.

BRIEF DESCRIPTION OF THE DRAWINGS

[00023] The invention is explained in greater detail below with reference to an exemplary embodiment that is illustrated in the accompanying figures.

[00024] FIG. 1 is a cross sectional view of an embodiment of a disk type axial flux wheel hub motor/generator in accordance with the invention.

[00025] FIG. 2 is a flow chart representing one possible implementation of switching controls used to implement the landing gear method in accordance with the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[00026] FIG 1. Shows the cross sectional view of a possible disk stack axial flux type wheel hub motor/generator used to accomplish the needed electromagnetic braking and/or motoring of the landing gear wheels.

[00027] The rotors 1 are coupled to the wheel 4 and rotate with the wheel 4. The stator disks 2, which may be constructed of an electrically conductive material, are coupled to the shaft 3 and/or central torque tube, and are stationary with respect to the wheel in which said disks are electrically isolated from each other except through available electrical connections (not shown). The rotor disks 1, which may be constructed of an electrically conductive material or may be constructed of permanent magnets, are coupled to the wheel 4. The wheel 4 is supported by means of a bearing set 5, which may be comprised of inboard and outboard bearing sets or a sleeve, air, or magnetic type bearing.

[00028] In the preferred embodiment, prior to touchdown the wheel 4 is motorized by applying power with a radial flow of electrical current through the stator disk 2 which generates an axial magnetic flux field which interacts with the axial magnetic flux field of the rotor disk 1 permanent magnets which are of a high energy density such as neodymium which are substantially located within the rotor disk 1 with an axial flux orientation in which all said permanent magnets are in the same vector direction. This embodiment develops a magnetic torque between the rotor disk 1 and stator disk 2, which causes the wheel 4 to experience a motor action. The stator disk 2 and/or rotor disk 1 may be comprised of aluminum, which may be coated with copper, which may be further coated with silver and/or may be comprised of any other alloy combination such as beryllium, copper and/or conductive polymer for increased strength. The electrical connections required are not shown, as the provision of electrical connections is well known. Such electrical connection may include, e.g., rolling contacts and/or sliding

carbon brushes. Alternatively, a brushless design may be used in order to accomplish the motor/generator action due to axial magnetic flux interactions described herein.

[00029] FIG. 2 shows the flow of the switching controls system signals and power signals used to accomplish the needed signals to control motoring and/or braking of the aircraft landing gear wheel hub motor/generator within a brushless design.

[00030] In the case of providing motor action to the wheel hub motor/generator the Hall effect sensors 1 are used to indicate the position of the permanent magnets wherein the magnets are alternating north and south poles with the flux aligned axially. The position information of the rotor disk is sent to the processor 3 for proper timing of control signals which are sent to the optical isolators 5 which are then sent to the polyphase brushless commutation driver control 10 which applies power from the power storage device and/or onboard power supply 9 to the stator field coils within a single stator disk 12 such that a motor action is produced either in the forward or reverse directions dependent upon the input from the user brake and motoring input control 7 which provides information to the processor 3 through the optical isolators 5 such as to initiate user input for forward or reverse motor action within the wheel hub motor/generator and the input from the parking brake controller 4 to the processor 3 is such that it indicates whether the parking brake friction braking system is engaged or not. An alarm 2 will activate if the parking brake is engaged and user input from the user brake and motoring input control 7 is initiating motor action. If the parking brake is disengaged the processor 3 will allow motor action in the forward or reverse direction as per the user input from the user brake and motoring input control 7.

[00031] In the case of providing generator action from the wheel hub motor/generator an electrical power connection is provided for from the stator field coils within a single stator disk 12 to the regenerative braking and polyphase rectification control 11 and as the relative motion occurs between the stator and rotor sections a polyphase power signal is generated within the wheel hub motor /generator stator coils and this power signal is sent to the regenerative braking and polyphase rectification control 11 which converts the varying polyphase power signal into a DC signal based upon control signals generated from the processor 3 which is dependent upon the input user control signals from the user brake and motoring input control 7. If the processor control signal is such that power storage and/or power dissipation is required then the DC power signal is sent from the regenerative braking and polyphase control 11 to the power storage device and/or onboard power supply 9 for later use and/or sent to a power dissipation resistor 13 for the dissipation of the generated electrical power. The regenerative braking and polyphase rectification control 11 may also be used to provide polyphase electrical power to the motorized braking control 6 which is controlled by processor 3 control signals in applying motorized braking commands as described within the preferred embodiment wherein polyphase power signals are applied to stator field coils of other stator disk 8 within the same or other wheel hub motor/generator disk stack such as to supply electrical power to stator field coils of other stator disk 8 which are experiencing generator action thus increasing the braking effect by motoring the disk in the opposite direction to that of the rotor rotational direction thus providing for a motorized braking effect which is unique in the area of brushless axial flux motors and generators.

[00032] Brushless axial flux motors and generators are well known in which the use of segmented rotor and stator sections are used. Variations of brushless axial flux motors and generators are taught within the following U.S. Patent No. 4,223,255, 4,567,391 4,585,085, 6,046,518, 6,064,135 6,323,573 B1, 6,617,748 B2 and 6,633,106 B1 also within the following application publications US 2003/0159866 A1 and US 2002/0171324 A1. Any axial flux type motor/generator also known as disk or pancake motors may be used incorporating the method of motorized braking as described within the patent including those which have yet to be issued patents. The rotors or stators are generally composed of permanent magnet segments such that there exist alternating north and south poles with the flux aligned axially. The rotor or stator sections generally consists of stator or rotor coils within a single stator or rotor disk attached to the stator or rotor disk with hall effect sensors which are also attached to the stator or rotor disk, which is also segmented as such to align the coil sets with that of the permanent magnets used within the rotor or stator. The stator or rotor coils within a single disk require controlled application of currents to said coils from a polyphase brushless commutation driver control such as to cause motor action. The control signals applied to such polyphase brushless commutation driver controls are generated from a processor through optical isolation using position information provided for by the Hall effect sensors. Such brushless motors may also be used in regenerative braking to supply electrical current by means of generator action and the electrical current path is provided for by means of electrical switching controls wherein the electrical power generated is stored for later use via a control system.

[00033] The possible forms of axial flux motors and/or generators may be summarized as follows. Generally the windings may be either stationary or rotary in which the windings may be incorporated into the following structures. One such possible structure is a slotted laminated or composite iron core material with the windings located within slots. Another possible structure is a slotless structure in which the windings are wound into coils those are embedded within an ironless structure or may be wound around a laminated or composite iron core material. A further possible structure is a solid structure in which induced currents circulate within a solid conducting material, which may or may not be a ferromagnetic material. Windings for a disk structure may be of printed circuit type and/or stamped from copper sheet and/or may be of copper windings wound into individual coils, which may or may not be of a litz wire construction.

USES

[00034] The instant after touch down the wheel hub motor/generator which is used as a motor may be converted so as to be used as a generator by discontinuing the application of power to the stator disk and drawing power from said stator disk due to the generator action that takes place when the magnetic field of the rotor disk is in relative motion with that of the stator disk such relative motion is due to the kinetic energy of the aircraft and by using well-known electrical switching action and controls such as electronically controlled switches such as IGBT's and/or electromechanical type relays such that generated electrical power may be stored and/or dissipated and/or applied to other stator disk which increases the braking effect by means of motorized braking.

[00035] The generated electrical current from the stator disk may be stored on the airplane by means of battery, capacitor banks or other suitable electrical power storage

devices such as a gyro and/or toroidal coil or coils that are electrically connected to the stator disk through the implementation of control electronics and/or physical contacts, thus allowing for dissipation and/or storage of electrical power generated for the purpose of supplying electrical power for later use.

[00036] Electromagnetic braking in its motorized braking method is preferably applied by using associated rotor and stator disk or disks as a generator whose output is applied to another stator disk or disks which then produces a motor action which is in direct opposition to the rotational direction of the wheel which generates a motorized braking action that exceeds that of regenerative braking alone, thus decreasing the braking distance and increasing the safety of the aircraft.

[00037] The method of motorized braking is preferably accomplished by two means. The first means is by the generated electrical power from one stator disk due to the relative motion of the associated rotor disk that may be applied to another stator disk within the wheel hub motor/generator disk stack in such a manner as to increase the braking effect by motoring the other associated rotor disk of said other stator disk in the opposite direction, thus accomplishing motorized braking or motoring of a disk or disks within the same or other wheel hub motor/generator disk stack as that of the generating disk or disks. The second means uses stored and/or onboard generated and/or external electrical power such that power is applied to the stator disk through provided electrical connections such that motor action is applied to the rotor disks in the opposite direction of rotation of the wheel thus accomplishing motorized braking or motoring of disk or disks within the wheel hub motor/generator. The two means above may be combined to produce the desired braking.

[00038] The axial flux wheel hub motor/generator may be used to provide for motor action to the aircraft landing gear wheels thus providing a gyroscopic stabilization effect to the aircraft. In a landing sequence the aircraft would deploy the landing gear and then apply a forward rotary motion to the aircraft landing gear wheels which will stabilize the aircraft due to the gyroscopic effect thus increasing the stability and safety of the aircraft.

[00039] Another embodiment uses eddy current braking as opposed to electromagnetic braking wherein the rotor disk are constructed of aluminum, aluminum alloy, steel, copper, beryllium, silver or any combination thereof of various constructions and the stator disk may be constructed as described above in the electromagnetic case of the previous preferred embodiment wherein the braking is accomplished by applying electrical current to the stator disk such that the magnetic field of the stator disk induces eddy currents within said rotor disk such that there is developed a magnetic torque which generates a braking action upon the wheel of said aircraft.

[00040] Any combination of the above embodiments may be used in addition to that of friction braking systems currently used, thus increasing the life and aiding the usefulness of the friction braking system as well as reducing the associated maintenance cost by reducing the rate of wear and the number of friction disk required. Cooling systems used for friction braking systems may also be employed in the above embodiments and embodiment combinations if needed.

[00041] In the case of a landing event the pilot deploys the landing gear and the landing gear wheel hub motor/generator is applied power by the pilot input controls such as to cause a forward rotation of the landing gear tires. The rotational velocity of a landing gear tire for a 130-mile per hour landing event for a typical 747 aircraft would be

approximately 48 rad/sec in order to match the tire and ground velocities thus greatly reducing the sliding friction wear of said tires. The instant after touchdown the control systems are used to store the generated electrical power from the wheel hub motor/generator thus providing regenerative braking. Then a few moments later the stored energy is applied to the wheel hub motors via the control system to cause motor action in the opposite direction than that of the rotational direction of the rotor thus providing for motorized braking. To cause the aircraft to come to a complete stop friction type brakes would be used which would also be used to apply a parking brake force to the landing gear wheels.

[00042] In the case of a takeoff event the pilot would initiate input controls such as to cause a forward rotation of the landing gear tires and power up the jet engines. This would cause the aircraft to travel down the runway faster than with the use of the jet engines alone thus reducing the needed runway distance for takeoff for a particular aircraft.

[00043] In the case of rejected takeoff all braking systems would engage in a manor such as to maximize the braking capacity of the aircraft.

[00044] In the case of the 180-degree turn ground maneuver the pilot would initiate input controls such as to cause one set of landing gear to be powered in the forward direction and the other set of landing gear to be powered in the opposite direction thus accomplishing the turning of said aircraft which is terminated under the control of the pilot.

[00045] In the case of aircraft carrier operations power supplied is from and external source of power via an attachment to the aircraft such as that used to propel or launch

aircraft off an aircraft carrier. The means of electrical connection can be a direct physical contact connector or a non-contact type that employs the use of magnetic induction to transfer the energy from a ground track to the aircraft. In such an implementation in commercial aircraft ground tracks could be incorporated into the runways of an airport such as to allow for power transfer and/or provide for a means in which aircraft control personnel could directly control ground movements of aircraft by controlling the power supplied to the aircraft wheel hub motor/generator thus increasing the level of control for the aircraft control personnel.

[00046] Although exemplary embodiments of this invention have been described, it in no way limits the scope within this invention. Those skilled in the art will readily appreciate that any modifications are possible and are to be included within the scope of this invention as defined in the following claims. In the claims, where means plus function clause are used, they are intended to cover the structural concepts described herein as performing the recited function and not only structural equivalents but also equivalent structures.

[00047] The method of the invention as described herein above in the context of the preferred embodiments is not to be taken as limited to all of the provided details thereof, since modifications and variations thereof may be made without departing from the spirit and scope of the invention. For example, the principles of the invention in their broader aspects may be applied to other motive and/or braking systems for electric vehicles such as trains, buses, trucks, cars, and boats or other electrically driven devices, which require braking.